Shielded Differential Connector Delivers Increased Bandwidth and Signal Integrity Performance

By

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Abstract

As system designers look to further increase performance by running backplane buses at frequencies > 500 Mhz, more advanced interconnect designs are necessary to meet bandwidth-density and signal integrity requirements. Overall backplane system bandwidth performance is dependent on close matching of the interconnect and backplane PCB performance. Adding stripline ground structures and external shielding in conventional “pin-n-socket” backplane interconnects has managed to improve signal integrity and bandwidth performance to some extent. However, use of advanced serial bus logic circuitry along with differential signaling and trace routing is creating board system designs with bandwidth performance at and beyond 2.5 Gbits/s, requiring further improvements in backplane interconnects. Metral® HB, a new backplane connector design optimized for differential signal routing, providing increased bandwidth performance greater than 6 Ghz, and containing advanced twin-
axial shielding structures that reduce multiline crosstalk to less than 2% @ 100 psec., will be discussed.

Introduction

Overall backplane system performance is dependent on well integrated board-level and interconnect design, with the bandwidth-density of the slowest segment being the limiting factor on system performance. Backplane interconnects must therefore have not only high bandwidth but also a high bandwidth density of routable data channels properly matched to pcb-board signal layers. Otherwise further increasing of interconnect density beyond the point where optimum system bandwidth density is achieved, will result in questionable use of resources.

The push for increased system bandwidth and data rates in telecom and datacom backplane applications has led to two general technical solution paths. The first solution is to simply increase the density of moderate speed parallel bus structures while the second solution focuses on relatively less dense, high data rate differential pair channels which, in the extreme, yields a third solution - the all cable backplanes used in some datacom applications. Each of these three backplane technologies requires a distinctly different approach to the design of the connectors used to tie the backplane system to the system daughter cards.

For any given system data transmission protocol there is usually a linear relationship between the desired system data rate in Gigabits/s and the required system 3db bandwidth in GigaHz. For example, using the fiber channel protocol, the available data rate is approximately four times the 3db system bandwidth. Therefore, all bandwidth considerations are referenced to the 3db bandwidth. The following analysis considers only differential pair data channels, but a similar analysis is also possible for single ended data channels.

Differential Pair PCB Backplane Bandwidth

The backplane data channels can use either edge coupled or broadside coupled differential pairs. However, since the edge coupled pairs can have a higher conductor-loss attenuation than a comparable broadside coupled pair, and because the bandwidth of the backplane system is limited by the data channel attenuation arising from conductor and dielectric losses, only broadside coupled pair data channels are considered in the following analysis. The attenuation of a data channel has two components, a square root of frequency term due to conductor losses and a linear term in frequency arising from dielectric losses (1).

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\text{where}
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\text{and}
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The pitch of the data channels is \( p \), \( w \) is the trace width, \( \rho \) is the resistivity of the PCB traces, and \( \varepsilon \) and \( DF \) are respectively the permittivity and dissipation factor of the PCB dielectric. For scaling, \( w/p \) is held constant at ~0.5 or less and \( Zo \) is held
constant by making the layer spacing between traces, h, proportional to p where h/p =0.2. The solution of (1) for A=3 db yields the 3db bandwidth of the data channel for a specific backplane length, L. In graphical form, these transmission line physical relationships illustrate how maximum bandwidth per channel decreases as you increase channel density. The bandwidth per channel for a 0.75m Speedboard™ backplane is shown in Figure 1. As the data channel pitch, p, decreases, the channel bandwidth decreases due to increasing conductor losses relative to the dielectric losses.

Figure 1.

For high performance backplanes, the bandwidth density per channel layer, BW/p, is the overall parameter that will determine optimum performance. One would hope that the performance benefit from increasing channel density occurs faster than the drop in each channel's bandwidth and that the total system bandwidth increases. However, as can be seen from the plot of bandwidth density vs. channel pitch for the Speedboard™ backplane shown in figure 2, the bandwidth density reaches a maximum at a channel pitch of approximately 1.2 mm. Any further decrease in channel pitch (i.e, increase in channel density), actually results in a decrease in bandwidth density and a decrease in system performance! This maximum in bandwidth density occurs when the conductor and dielectric losses are approximately equal.

Figure 2.

Metral® HB Connector Bandwidth

The bandwidth of a connector is determined primarily by the extent of reflections between internal geometrical and impedance discontinuities, and modal dispersion,
not attenuation. Therefore, the "channel bandwidth" is to first order a constant and relatively independent of the connector signal to ground ratio, which in typical pin and socket connectors determines the "data channel" density, i.e., the lower the signal-ground ratio the lower the channel density. The bandwidth density is then a linear function of the data channel density. To improve bandwidth performance, the Metral® HB connector geometry was designed to minimize wherever possible the number and magnitude of impedance discontinuities within the differential signal path. Differential Characteristic Impedance of an eight row board-to-board configuration measures 110-120 Ohms, with a step response risetime of 32 psec. (10/90 %). Bandwidth measurements, at the 3db point are > 6 Ghz. Figure 3, contains a plot of bandwidth as a function of bandwidth density for the Metral® HB connector showing a rectangular area bounded by the channel bandwidth and by the maximum bandwidth density. Since backplane connector performance can be characterized in terms of the bandwidth per channel vs. bandwidth density per layer plane, it is a natural extension to characterize backplane PCB systems in terms of this "phase plane" representation. A plot of bandwidth per channel vs. bandwidth density per layer for a 0.75m Speedboard™ backplane is also shown in Figure 3, where the channel pitch is the independent variable. It is clearly evident that, for a given bandwidth density per layer, there are two possible configurations with the same solution, i.e., a high channel density low channel bandwidth "parallel" solution, and a low channel density high channel bandwidth "serial" solution. How well the plot of the connector overlaps that of the backplane system is an indication of how well the connector is "matched" to that particular backplane. As illustrated in figure 3, the Metral® HB connector represents an excellent match with system performance of next-generation, advanced substrate backplanes.

![Figure 3.](image)

**Differential Pair & Shielding Structure**

The Metral® HB contact design creates differential pairing by coupling adjacent row-based signal pairs. As illustrated in figure 4., row-based coupling eliminates intra-pair differential skew concerns that are generated by the difference in stripline connectors' column-shielded, right-angle daughtercard connector tail paths.
Figure 4.

Noted on the close-up cross-section in figure 5, center-to-center spacing between coupled signal pairs is 1.3mm. This close “intra-pair” coupling maximizes the difference between the differential (odd) and common (even) mode impedances, and allows inclusion of inverted "L" shaped shielding structures around each signal contact creating a twin-axial like shielding effect. This enhanced shielding, by sharply attenuating "inter-pair" coupling, minimizes the effects of modal dispersion by reducing the number of modes to only local even-odd modes. An important side benefit of this decoupling is reduced crosstalk. Test results of multiple active near-end crosstalk @ 100 psec. risetimes (10-90%), generated values of less than 2%. In contrast to stripline shielded connectors, this twin-axial configuration minimizes row-to-row x-talk, without requiring use of signal positions for grounding, preserving I/O density. Results indicate most of the crosstalk appears to be concentrated in the transition to the board footprint / trace area. Each Metral® HB differential pair, along with its corresponding shielding structures can be stacked on a column-to-column pitch of 4mm, and a row-to-row pitch of 2mm. Given this configuration, the resultant “usable signal density” then becomes equivalent to an open pin field 2mm x 2mm connector. For example, an 8-row Metral® HB module pin field will have an equivalent signal density of 101 signals per linear inch of PCB card edge.

Figure 5.

The twinax structure of the receptacle design is further illustrated in figure 6. The figure depicts two 8-row differential columns stacked side to side. Each differential column has 16 signal and ground contacts. This side-by-side stacking construction allows for adjacent "mirror image" ground contact shields to share the same PCB plated-through-hole, reducing the overall number of required holes and facilitating board trace routing around the connector footprint. These signal / ground contact structures are then loaded into a receptacle housing shell to complete the finished receptacle package. It should be noted that this is achieved without adversely impacting ground inductance.
PCB Trace Routing Options

As discussed earlier, channel routing configurations on the PCB are a critical parameter in determining overall backplane system bandwidth-density performance. Metral® HB’s connector PCB footprint enables routing of two differential traces (two traces = one channel), either edge or broadside coupled, on a channel-layer pitch of 2mm closely matching the optimal bandwidth density point of high performance backplanes. Detailed layouts of the edge coupled and broadside coupled trace routing options are shown in figures 7, and 8, respectively.

Figure 7.
Mechanical Reliability

Along with high-speed signal integrity and electrical performance, mechanical reliability is an equally important criteria for next-generation backplane interconnects. The subject connector's electrical performance was accomplished while maintaining established mechanical design constructs for backplane interconnect reliability. Metral® HB is a two piece backplane connector with a pin-n-socket contact design on both ground and signal connections. On high-density backplanes two redundant points of contact with generous wiping action reduce the possibility that random contaminants might cause contact resistance instability. The pin-n-socket interface allows for generous wiping action during mating (2mm minimum on the shortest pin), and has two redundant points of contact. Contact surfaces are plated with a Gold finish over Palladium-Nickel for improved corrosion protection and extended durability. Each compliant cantilever beam contact is designed for a minimum normal force > 50 grams E-O-L (end-of-life). In contrast to a one-piece connector, using a two-piece connector will offer better control of critical mating surface tolerances, alignments, and platings. Unless signal density sacrifices are made, one-piece connectors typically cannot incorporate redundant points of contact. Additionally, one-piece (card edge) connectors encounter a much wider tolerance range of board thicknesses, along with PCB bowing and warp issues that have to be accommodated at the contact interface. Metral® HB 's module attachment to the backplane and daughtercard PCB is accomplished with proven E-O-N (eye of the needle), permanent press-fit terminations. The two-piece housings contain keying an polarizing features with generous lead-in capture geometry and are constructed of high-strength, dimensionally stable (even at high reflow-process temperatures) liquid crystal polymer (LCP). To improve mechanical mating / unmating ruggedness, the connector's pin header housings incorporate side wall supports for added protection of vulnerable pins on end columns locations. The pin header connector also easily accommodates sequenced engagement by allowing for staggered mating pin heights. Sequenced mating helps protect sensitive circuitry from disruptive electrical charges, and reduces overall connector / card-slot peak insertion forces. Because both differential signal and ground separable interfaces use pin-n-socket style contacts, midplane applications can be configured with conventional, long tail header / rear-plug-up shrouds similar to those currently used on standard open pin field 2mm connectors such as Metral®, Millipacs 1™, and Millipacs 2™. Figure 9 depicts an eight row 80 signal (40 differential pairs), 24mm wide Metral® HB header module, and figure 10 displays a corresponding mating receptacle module.
Modularity

In order to facilitate integration of this new connector into future backplane applications, current backplane form factors and dimensional practices were incorporated wherever possible. The connector was designed in a modular format in six and eight row configurations. Additional module sizes of 48mm and 96mm, containing 80 and 160 differential pairs respectively, are in development. The modules are end-to-end stacking compatible with 2mm backplane connector packaging conventions. Board layout dimensions such as distance from the motherboard PCB plane surface to the daughtercard edge, distance to the first row of plated-through-holes on the daughtercard, and header standoff heights, meet EIA / IEC industry standards for Futurebus+ connectors. (Reference figure 11.) (2)

Conclusion
Differential signaling technology is advancing rapidly allowing development of systems operating at frequencies well above 500 MHz. At these high frequencies, interconnects must be designed to minimize impedance discontinuities and maximize electromagnetic isolation between differential pair channels. The system analysis has demonstrated how high-speed backplanes require precise integration of bandwidth performance amongst the interconnect and PCB subsystems. A two-piece connector design containing twin-axial shielding structure and interface geometry optimized for differential signaling in a manner closely matching bandwidth-density capabilities of hybrid-substrate, high-performance PCB's has been proposed. Also of note, the subject connectors mechanical design follows established conventional practices for interconnect reliability and is offered in a modular fashion, facilitating incorporation into existing backpanel geometric formats.

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